Public Health Impacts of Old Coal-Fired Power Plants in Michigan

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Who We Are

Since 1980, the Michigan Environmental Council has been at the forefront of efforts to protect our Great Lakes, promote sustainable cities, safeguard public health and establish clean energy policies for a more vibrant economy. Representing over 60 member organizations throughout the state, MEC provides agenda-setting leadership at the State Capitol and with our Congressional delegation in Washington.

About the Author

Environmental Health & Engineering, Inc. (EH&E) is a professional services firm established in 1987 to provide businesses and institutions with a reliable resource for environmental consulting and engineering services. The company is composed of 75 highly trained individuals based in Needham, Massachusetts, who share a passion and enthusiasm for excellence.

This project for the Michigan Environmental Council was led by David L. MacIntosh, Sc.D., C.I.H. In addition to his role as a Principal Scientist and Associate Director of Advanced Analytics and Building Science at EH&E, Dr. MacIntosh is an Adjunct Associate Professor of Environmental Health at the Harvard School of Public Health where he teaches a course on environmental exposure assessment to masters and doctoral degree students. Dr. MacIntosh also is a technical advisor to the World Health Organization and is the first-draft author of several publications for that organization including a Toolkit for Human Health Risk Assessment which was published in 2011.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACS	American Cancer Society
AHSMOG	Adventist Health and Smog
BenMAP	Environmental Benefits Mapping and Analysis Program
C-R	concentration-response
COI	cost-of-illness
COMEAP	Committee on the Medical Effects of Air Pollutants
CRDM	Climatological Regional Dispersion Model
EGU	electricity generating unit
EH&E	Environmental Health & Engineering, Inc.
EPA	U.S. Environmental Protection Agency
ER	emergency room
GIS	Geographic Information System
HIA	health impact assessment
ICD-9	International Statistical Classification of Diseases
MRAD	minor restricted activity days
MW	megawatt
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NCHS	National Center for Health Statistics
NEI	National Emissions Inventory
NHDS	National Hospital Discharge Survey
NO_X	nitrogen oxides or oxides of nitrogen
S-R	Source Receptor
$PM_{2.5}$	particulate matter that is 2.5 micrometers or smaller in size
PM_{10}	particulate matter that is 10 micrometers or smaller in size
SO_2	sulfur dioxide
TSP	total suspended particulates
VA	Veterans Administration
VSL	value of statistical life
U.S.	United States
WTP	willingness-to-pay
$\mu g/m^3$	micrograms per cubic meter

1.0 EXECUTIVE SUMMARY

Environmental Health and Engineering Inc. (EH&E) estimated the public health impacts expected due to airborne particulate matter less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$) attributable to emissions from nine coal-fired electricity generating units (EGUs) which began operation in the State of Michigan between 1949 and 1968. A recent study released by the National Academy of Sciences found that the dirtiest (strongly correlated with the oldest) 10% of the plants, accounted for 25% of the generation and 43% of the public health damages borne by people living in the United States (U.S.) (NRC, 2010).

We estimate the Michigan-specific health-related damages associated with $PM_{2.5}$ emissions from the nine coal-fired facilities to be $1.5 billion annually and the national impacts from those same facilities to $5.4 billion annually. The nine Michigan EGUs included in this analysis are listed in Table 1.1.

Table 1.1 Electricity Generating Units Included in Assessment of Public Health Impacts Associated with Air Pollutant Emissions from Older Coal-fired Power Plants in Michigan

Electricity Generating Unit	Parent Company	County	Initial Startup Year	Nameplate Capacity of Modeled Units (MW)	Approximate Coal Consumption (tons/year)*
BC Cobb**	CMS Energy	Muskegon	1956	313	900,000
Dan E Kar**n	CMS Energy	Bay	1956	544	1,500,000
JC Weadock**	CMS Energy	Bay	1955	313	800,000
Harbor Beach	DTE Energy	Huron	1968	121	100,000
JH Campbell**	CMS Energy	Ottawa	1962	669	1,600,000
JR Whiting	CMS Energy	Monroe	1952	345	1,000,000
River Rouge	DTE Energy	Wayne	1957	651	1,300,000
St. Clair	DTE Energy	St. Clair	1953	1,547	3,000,000
Trenton Channel	DTE Energy	Wayne	1949	776	1,700,000

MW megawatts

* Based on conversion of million BTUs to tons of bituminous coal published by the U.S. Department of Energy. http://www.energystar.gov/ia/business/tools_resources/target_finder/help/Energy_Units_Conversion_Table.htm

** Values do not include boilers that began operation after 1969.

Our estimates were derived by applying a widely accepted methodology for conducting health impact assessments of air pollutants which is used by the U.S. Environmental Protection Agency (EPA) to evaluate policy options. Our analysis is grounded in the scientific conclusions reached by EPA and its independent scientific advisors that inhalation of $PM_{2.5}$ over both short and long periods of time is a cause of cardiovascular effects, including heart attack and the associated mortality (EPA, 2009; CASAC, 2010).

Particulate matter, also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of substances, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. Fine particulate matter or $PM_{2.5}$ is well-known by health professionals because of its connection to a wide variety of health ailments. Combustion of fossil fuels is the primary source of $PM_{2.5}$ in the atmosphere. Air pollutants generated by burning coal to generate electricity are the largest components of $PM_{2.5}$ in the eastern U.S.

Fine particles can affect the heart and lungs and cause serious health effects. When inhaled by people, some $PM_{2.5}$ particles deposit along the respiratory tract, while others penetrate deeply into the lung where they can enter the bloodstream. These particles (i) aggravate the severity of chronic lung diseases and impair airways function, and (ii) cause inflammation of lung tissue which results in the release of chemicals that impact heart function, and leads to changes in blood chemistry that produces clots which can cause heart attacks (EPA 2010a).

Health impact assessments of the type we conducted for selected EGUs in Michigan combine information on changes in air pollutant concentrations, the relationship between air pollutant concentrations and the risk of an adverse health outcome, the baseline incidence of each health outcome, and the size of the population exposed to the air pollutants.

Our analysis considered the following health outcomes: premature mortality, hospital admissions for cardiovascular and respiratory disease, emergency room (ER) visits for asthma, asthma exacerbation, chronic bronchitis, and minor restricted activity days (MRADs). The annual number of cases of each health outcome associated with air

pollutant emissions from the Michigan coal-fired EGUs facilities was estimated for each county in the continental U.S. By conducting our analysis at the resolution of counties rather than a larger geographic area (e.g., state), we maintained spatial relationships among population sizes, baseline incidence of disease, and air quality important for ascertaining a reasonable estimate of public health impacts associated with pollutant emissions from the eleven modeled Michigan EGUs.

As shown in Table 1.2, 180 premature deaths per year in Michigan are expected to be associated with particle emissions from the nine modeled Michigan EGUs. Our estimates of the annual morbidity-related impacts (e.g., hospital visits, asthma attacks, etc.) in Michigan associated with air pollutant emissions from the coal-fired Michigan EGUs are summarized in Table 1.2 as well. Approximately 230 hospital admissions or ER visits and 68,000 asthma exacerbations in Michigan each year are estimated to be associated with these older Michigan-based coal-fired facilities.

Table 1.2 Annual Mortality and Morbidity Impacts in Michigan Associated with Air Pollutant Emissions from Older Coal-fired Electricity Generating Units in Michigan

Outcome	Cases
Premature mortality	180
Cardiovascular hospital admissions	38
Respiratory hospital admissions	55
Chronic bronchitis	76
Asthma emergency room visits	140
Asthma exacerbations	68,000
Minor restricted activity days	72,000

Public health impacts across the entire U.S. associated with emissions from the Michigan EGUs are presented in Table 1.3. The number of adverse health outcomes annually includes 660 premature deaths, 360 hospital admissions for cardiovascular or respiratory disease, 450 ER visits for asthma, 250,000 asthma exacerbations (e.g., asthma attacks), 280 new cases of chronic bronchitis, and approximately 260,000 minor restricted activity days.

Table 1.3 Annual Mortality and Morbidity Impacts in the Continental United States Associated with Particulate Matter-related Air Pollutant Emissions from Older Coal-fired Electricity Generating Units in Michigan

Outcome	Cases
Premature mortality	660
Cardiovascular hospital admissions	150
Respiratory hospital admissions	210
Chronic bronchitis	280
Asthma emergency room visits	450
Asthma exacerbations	250,000
Minor restricted activity days	260,000

We estimate the annual national and Michigan-specific health-related damages associated with $PM_{2.5}$ emissions from the nine coal-fired EGUs to be $5.4 billion and $1.5 billion respectively. Table 1.4 displays the EGU specific impacts.

Table 1.4 Valuation of Annual Plant-specific Public Health Damages Associated with Contributions of Older Coal-fired Power Plants in Michigan to Fine Particle Levels in Air

Electricity Generating Units	Economic Value ($ million)	
	Michigan*	Continental U.S.
BC Cobb	68	450
Dan E Karn / JC Weadock	120	720
Harbor Beach	11	63
JH Campbell	150	700
JR Whiting	560	1,040
River Rouge	340	780
St. Claire	65	560
Trenton Channel	140	1,080
Total	1,500	5,400

A significant portion of the public health impacts are anticipated to be realized in the states of the upper Midwest and Northeast—Illinois, Indiana, Ohio, Pennsylvania, New York—states that are proximate or downwind to the coal-fired EGUs included in this assessment. As an illustration of this point, Figure 1.1 contains a map that provides the number of premature deaths associated with the modeled EGUs in each state. Health impacts for the morbidity endpoints are distributed similarly across the states.

The basis of the estimated public health impacts is the increment of $PM_{2.5}$ in each county that is estimated to result from emissions from the Michigan coal-fired EGUs. The

incremental annual average exposure to $PM_{2.5}$ is centered in Michigan, extending east to the Atlantic Ocean, and as far west as Colorado. An illustration of the geographic distribution of the incremental annual average $PM_{2.5}$ levels associated with emissions of $PM_{2.5}$ and particle precursors from the Michigan coal-fired EGUs is presented in Figure 1.2.

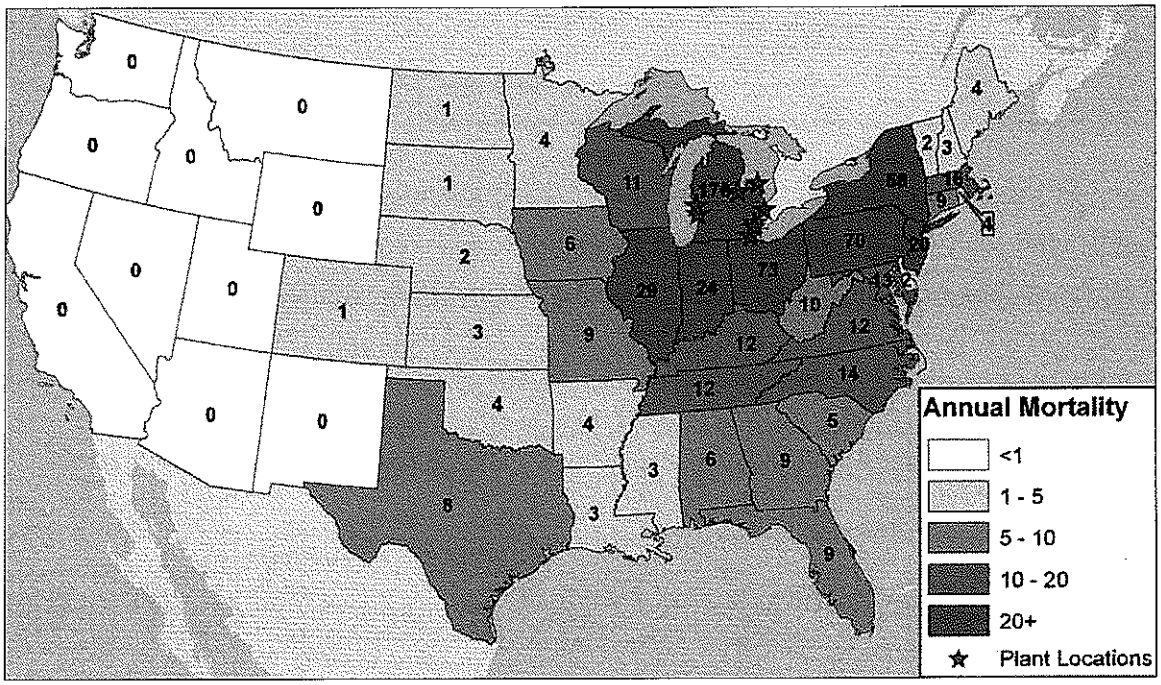

Figure 1.1 Estimated Number of Fine Particle-related Premature Deaths for Each Year Associated with Emissions from Older Coal-fired Electricity Generating Units in Michigan

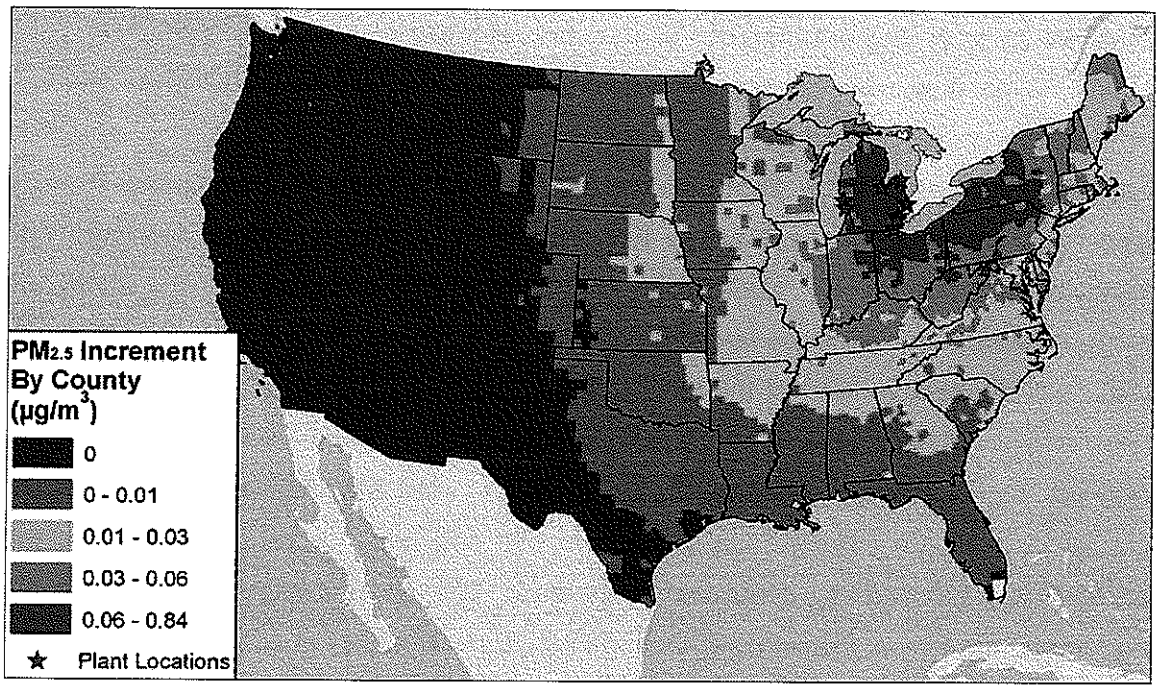

Figure 1.2 Estimated Annual Average Increment of Fine Particle Concentrations ($\mu g/m^3$) Associated with Older Coal-fired Electricity Generating Units in Michigan

The reasonableness of our estimates is informed by the widely accepted nature of our methodology and the similarity between our outputs and those from related studies. The methodology used has been widely vetted in the scientific and regulatory community and is used by the EPA to report to the U.S. Office of Management and Budget and others on the benefits of various air pollution control programs. The method used to incorporate the more recent literature on air pollution associations with premature mortality and morbidity is widely accepted and used as a matter of routine in meta-analysis of multiple studies on various topics, not just health effects of air pollution. The method to predict $PM_{2.5}$ concentrations, the Source Receptor Matrix is an EPA model that has been used in a number of regulatory impact assessments. The body of epidemiological literature for health effects of particulate matter is large and robust, and is supported by good mechanistic understanding of how particulate matter can influence human health. Had we included the population of Southeast Canada and used forecasted future population values for 2010 rather than population information from the 2000 Census, the estimates of public health impacts would have been substantially greater.

Additionally, consideration of pollutants other than $PM_{2.5}$, such as mercury, could have further increased our public health impact estimates. Electricity generating stations

powered by coal account for 58% of mercury released to air in Michigan from point sources. Coal-fired power plants can be significant contributors to deposition of mercury on soil and water, reportedly accounting for 70% of the mercury present in rainfall in eastern Ohio (Keeler et al., 2006). Mercury that deposits to the earth's surface from air can make its way into waterways where it is converted by microorganisms into methylmercury, a highly toxic form of mercury (Grandjean 2010). As these microorganisms are eaten by larger organisms, methylmercury concentrations increase with each successive level of the food chain, in a process called bioaccumulation. The large and long-lived predators of marine and freshwater ecosystems, including many fish favored by consumers in the U.S., end up with the highest methylmercury concentrations. As a result, consumption of fish and other aquatic organisms is the predominant pathway of exposure to mercury. The amount of mercury in people correlates with typical fish intake (MacIntosh et al., 1997; Carta et al., 2003; Mozaffarian and Rimm, 2006). Methylmercury is a potent neurotoxin, and high accumulation in humans is a cause of brain damage, while lower body burdens are associated with impairment of people's ability to learn and fine motor control, and may be a factor in heart disease. Because of concern about the effect of methylmercury on the developing brain, numerous government agencies have issued recommendations on fish consumption to minimize dietary intake of mercury for women who are or may become pregnant, nursing mothers, and young children. One in six women in Michigan are reported to have body burdens of mercury that exceed values recommended by health protective agencies.

In summary, the approach and inputs to our calculations of the premature mortality and annual morbidity associated with particulate emissions from coal-fired Michigan EGUs are reasonable. Premature mortality and morbidity attributable to fossil fuel-related particulate matter persists in the U.S. and reduction in emissions from coal-fired power plants will have health benefits of the magnitude estimated within this report.

We have estimated that the nine modeled coal-fired EGUs release approximately 11,300 tons of $PM_{2.5}$ and 194,000 tons of sulfur dioxide and nitrogen oxides per year. As a consequence, millions of people across the country, but especially in the upper Midwest and Northeast are exposed to $PM_{2.5}$ and other pollutants. Each year these facilities operate, approximately 180 lives are lost prematurely in Michigan. But since the

byproducts of coal-fired power plant emissions are dispersed over great distances, over 480 additional lives are lost annually in 39 other states influenced by these sources. Furthermore, we estimate that 30 lives per year would be lost prematurely in impacted areas of Canada. Other important health impacts, such as asthma morbidity, chronic bronchitis, hospital admissions due to pollutant exposures are associated with emissions from these EGUs.

2.0 INTRODUCTION

The purpose of this report is to present our assessment of the health impacts associated with changes in $PM_{2.5}$ concentrations estimated to result from a reduction in air pollutant emissions from nine coal-fired electricity generating units (EGUs) operated in the state of Michigan. Attributes of the nine EGUs are reported in Table 2.1, with a combined nameplate capacity of 5,279 megawatts (MW), equivalent to approximately 20 percent of Michigan's total capacity. The general approach and specific methods that we used in this assessment are detailed in Section 3. The results of our health impact assessment are presented in Section 4. Conclusions drawn from our work are summarized in Section 5 and detailed results are presented in Appendix A and Appendix B. A description of EH&E is presented in Appendix C.

Table 2.1 Power Plants Included in Assessment of Public Health Impacts Associated with Air Pollutant Emissions from Older Coal-fired Electricity Generating Units in Michigan

Electricity Generating Unit	Parent Company	County	Initial Startup Year	Nameplate Capacity of Modeled Units (MW)	Approximate Coal Consumption (tons/year)*
BC Cobb**	CMS Energy	Muskegon	1956	313	900,000
Dan E Karn**	CMS Energy	Bay	1956	544	1,500,000
JC Weadock**	CMS Energy	Bay	1955	313	800,000
Harbor Beach	DTE Energy	Huron	1968	121	100,000
JH Campbell**	CMS Energy	Ottawa	1962	669	1,600,000
JR Whiting	CMS Energy	Monroe	1952	345	1,000,000
River Rouge	DTE Energy	Wayne	1957	651	1,300,000
St. Clair	DTE Energy	St. Clair	1953	1,547	3,000,000
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MW megawatts

* Based on conversion of million BTUs to tons of bituminous coal published by the U.S. Department of Energy. http://www.energystar.gov/ia/business/tools_resources/target_finder/help/Energy_Units_Conversion_Table.htm

** Values do not include boilers that began operation after 1969.

4.0 RESULTS

4.1 PUBLIC HEALTH IMPACTS

Our analysis of public health impacts is based on the modeled differences in population exposure to $PM_{2.5}$ if the emissions from the nine modeled EGUs in Michigan were eliminated. The results reflect estimated public health impacts of the proposed controls on a yearly basis.

Approximately 281 million people lived in the United States in 2000. In this population, 163 million are adults older than 29 years, 4 million are infants under one year, and 72 million are children under 18 years. Between 2000 and 2010 this population grew by approximately 27 million people.[3] The average age of the U.S. increased as well.[4] The increase in average age of the population means that if public health impacts were estimated for 2010, the results would be even greater than our estimates based on the 2000 Census data.

Our estimates of the annual health-related impacts in Michigan associated with reduced air pollutant emissions from the coal-fired EGUs are summarized in Table 4.1. One hundred and eighty (180) premature deaths are estimated to be avoided among the residents of Michigan for each year that the EGUs plants are operated. Morbidity impacts estimated as a result of reduced emissions from EGUs include 68,000 asthma exacerbations, and 72,000 MRADs avoided. Public health impacts attributable to $PM_{2.5}$ for each Michigan county are presented in Table A.1 in Appendix A.

[3] http://www.census.gov/prod/cen2010/briefs/c2010br-01.pdf
[4] http://www.census.gov/prod/cen2010/briefs/c2010br-03.pdf

Table 4.1 Annual Mortality and Morbidity Impacts in Michigan Associated with Air Pollutant Emissions from Older Coal-fired Electricity Generating Units in Michigan

Outcome	Cases
Premature mortality	180
Cardiovascular hospital admissions	38
Respiratory hospital admissions	55
Chronic bronchitis	76
Asthma emergency room visits	140
Asthma exacerbations	68,000
Minor restricted activity days	72,000

Our estimates of premature mortality and morbidity impacts for the entire U.S. population for each year are presented in Table 4.2. The estimates include 660 premature deaths and approximately 800 hospital admissions or ER visits, and 250,000 exacerbations of asthma (e.g., an asthma attack) avoided for each year of controls. Over 260,000 MRADs are also estimated to be avoided annually.

Table 4.2 Annual Mortality and Morbidity Impacts in the Continental United States Associated with Particulate Air Pollutant Emissions from Older Coal-fired Electricity Generating Units in Michigan

Outcome	Cases
Premature mortality	660
Cardiovascular hospital admissions	150
Respiratory hospital admissions	210
Chronic bronchitis	280
Asthma emergency room visits	450
Asthma exacerbations	250,000
Minor restricted activity days	260,000

Annual public health impacts for each state are listed by health endpoint in Table A.2 in Appendix A. After Michigan, the states with the greatest health impacts were Ohio, Pennsylvania, New York, and Illinois. The geographic distribution of public health impacts is a function of the patterns of incremental $PM_{2.5}$ exposure as well as the size and location of at-risk populations.

The geographic distribution of estimated public health impacts is illustrated in Figure 4.1 using premature deaths as an example. The impacts are most pronounced in the upper Midwest. Maps of state-specific estimates of total hospital impacts and asthma exacerbation impacts are provided in Figures B.1 and B.2 of Appendix B.

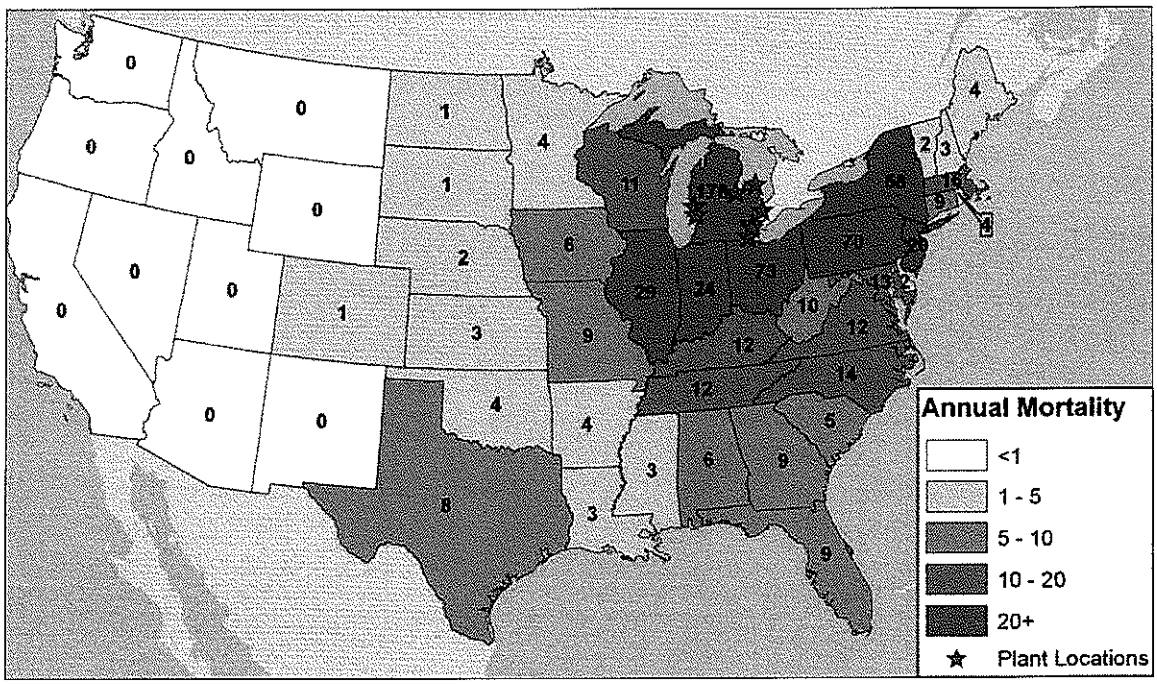

Figure 4.1 Estimated Number of Premature Deaths for Each Year Associated with Fine Particle-related Emissions from Older Coal-fired Electricity Generating Units in Michigan

As described earlier, we determined the incremental change in population exposure to annual average $PM_{2.5}$ concentrations associated with emissions from nine coal-fired EGUs in Michigan for each county in the U.S. As shown in Figure 4.2, the Michigan counties with the greatest incremental change in annual average $PM_{2.5}$ exposure were in central and eastern Michigan, with the largest impacts in Monroe, Wayne and St. Clair counties. In Michigan, approximately 2.5 million people live in counties predicted to have a incremental reduction greater than 0.25 $\mu g/m^3$, 2.1 million with a reduction of 0.15 to 0.25 $\mu g/m^3$, 1.6 million with a reduction of 0.1 to 0.15 $\mu g/m^3$, 2.9 million with a reduction of 0.05 to 0.1 $\mu g/m^3$, and 800,000 people with a reduction of less than 0.05 $\mu g/m^3$.

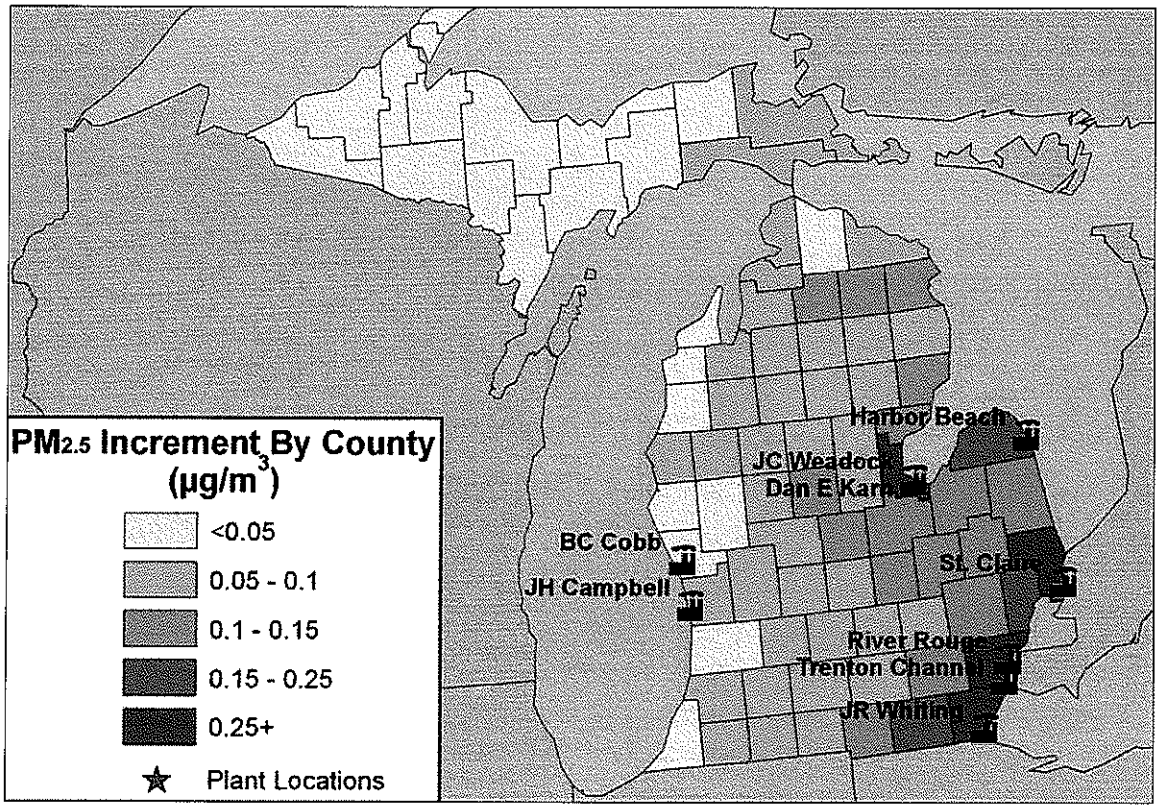

Figure 4.2 Annual Average Fine Particle Concentrations ($\mu g/m^3$) in Michigan Associated with Emissions from Older Coal-fired Electricity Generating Units in Michigan

In the continental U.S., approximately 26 million people live in counties predicted to have a incremental reduction greater than 0.06 $\mu g/m^3$, 48 million with a reduction of 0.03 to 0.06 $\mu g/m^3$, 99 million with a reduction of 0.01 to 0.03 $\mu g/m^3$, and 103 million with a reduction of less than 0.01 $\mu g/m^3$ (see Figure 4.3).

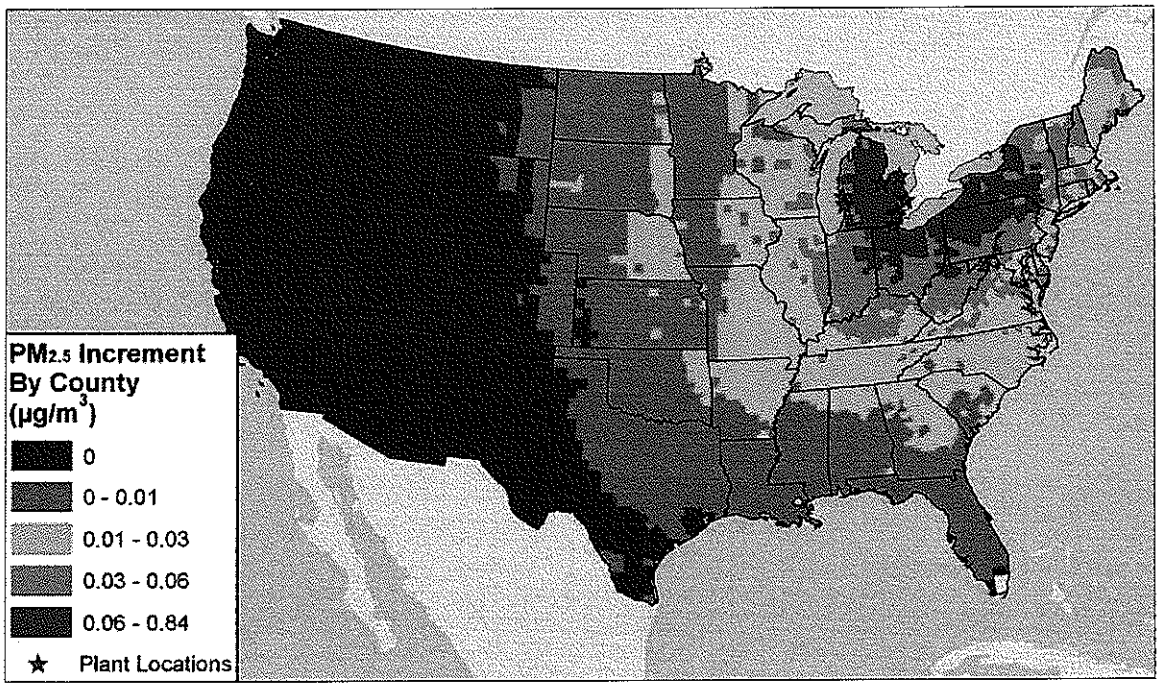

Figure 4.3 Annual Average Increment of Fine Particle Concentrations ($\mu g/m^3$) in the Continental U.S. Associated with Emissions from Older Coal-fired Electricity Generating Units in Michigan

4.2 POTENTIAL IMPACTS FOR CANADA

One assumption that clearly represents an underestimate of the public health impacts associated with the modeled EGUs is limiting the modeling domain to the continental U.S. The S-R Matrix does not include Canada and therefore it is not possible to quantitatively determine the impacts to the Canadian population. However, the areas in Southeastern Ontario east of Michigan have the largest population and highest population densities in Canada, and would undoubtedly be impacted by emissions from the modeled EGUs. Statistics Canada estimates that approximately 9 million people live in the area highlighted in Figure 4.4 that would be most impacted by emissions from the modeled EGUs. As shown in Figure 4.4, we would expect the incremental $PM_{2.5}$ concentration for the majority of southeast Ontario to be at least 0.06 $\mu g/m^3$. Using that assumption, and a published value for baseline mortality incident rates in Canada (Public Health Agency of Canada 2010), we estimate that the premature mortality impacts due to emissions of the modeled EGUs in Canada to be at least 30 additional cases of premature mortality per year.

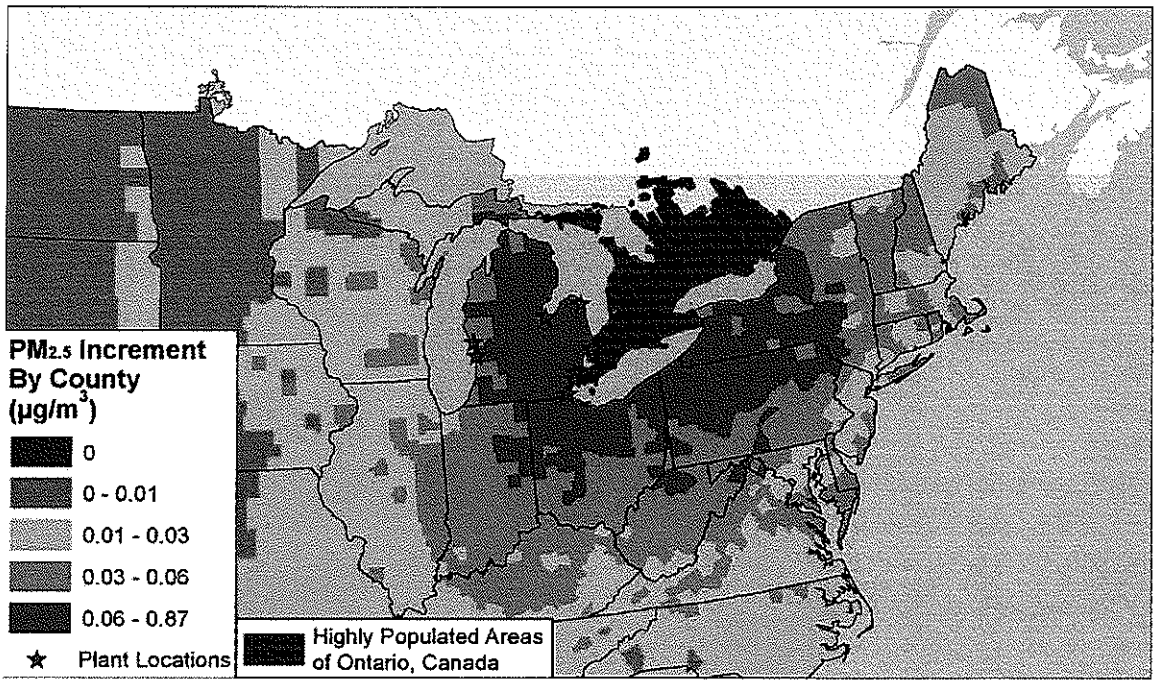

Figure 4.4 Annual Average Increment of Fine Particle Concentrations ($\mu g/m^3$) in the Upper Midwest and Northeast Associated with Michigan Coal-fired Electricity Generating Unit Emissions

4.3 ECONOMIC VALUATION OF PUBLIC HEALTH IMPACTS

We estimate the annual national and Michigan-specific health-related damages associated with $PM_{2.5}$ emissions from the nine coal-fired EGUs to be $5.4 billion and $1.5 billion respectively. Table 4.3 displays the EGU specific impacts. The underlying incremental health impacts are presented in Table 4.4, which depicts the annual mortality and morbidity impacts for Michigan and the continental U.S. It should be noted that all of the estimates above are rounded to whole numbers.

Table 4.3 Valuation of Annual Plant-specific Public Health Damages Associated with Contributions of Older Coal-fired Power Plants in Michigan to Fine Particle Levels in Air

Electricity Generating Units	Economic Impact ($ million)	
	Michigan*	Continental U.S.*
BC Cobb	68	450
Dan E Karn / JC Weadock	120	720
Harbor Beach	11	63
JH Campbell	150	700
JR Whiting	560	1,040
River Rouge	340	780
St. Claire	65	560
Trenton Channel	140	1,080
Total	1,500	5,400

Table 4.4 Valuation of Annual Outcome-specific Public Health Damages Associated with Contributions of Older Coal-fired Power Plants in Michigan to Fine Particle Levels in Air

Plant	Economic Impact ($ million)	
	Michigan	National
Premature mortality	1,440	5,300
Cardiovascular hospital admissions	1	4
Respiratory hospital admissions	1	3
Asthma emergency room visit	0.05	0.2
Asthma exacerbation	3	13
Chronic bronchitis	33	120

4.4 REASONABLENESS OF HEALTH IMPACT ESTIMATES

In this section, we discuss some of the assumptions within our analysis and their implications to demonstrate that our approach to calculating the annual mortality and morbidity impacts from the removal of emissions from the nine coal-fired EGUs is reasonable.

One assumption that slightly underestimates the public health impacts is the utilization of 2000 population information from the 2010 U.S. Census. The population of Michigan over that time period is expected to be stable, however, the population in the U.S. is expected to increase by 39 million people (Woods and Poole Economics 2006).

For the concentration-response functions derived above, alternative values could have been determined that may have either increased or decreased the public health impacts estimates. For example, for premature mortality from $PM_{2.5}$, the 12 expert opinions from the an expert elicitation (Industrial Economics 2006) gave median concentration-response functions ranging from 0.4% to 2.0% (versus our estimate of 1.0%). Therefore, applying either of the extreme values could either double or halve our public health impact estimates. However, neither would represent the best interpretation of the current scientific literature in our view. Had we used the median value among the expert opinions, our estimate of premature mortality impacts would have differed (increased) by only 5% from our present estimates.

Our estimates of public health impacts are also influenced by the baseline incidence of mortality and morbidity used in the HIA calculations. Our incidence estimates reflect the best information currently available. However, rates may change as the population ages, as medical science advances, and as health care practices evolve. Specifying the direction and magnitude of the influence of these factors (and others) on baseline incidence of mortality and morbidity related to $PM_{2.5}$ are beyond the scope of this analysis. However, the net effect of these factors would have to be on the order of 10% or more to be significant compared to the effect of the forecasted population growth.

In general, the reasonableness of our estimates is informed by the widely accepted nature of our methodology and the similarity between our outputs and those from related studies. As discussed above, the methodology used has been widely vetted in the scientific and regulatory community and is used by the EPA to report to the U.S. Office of Management and Budget and others on the benefits of various air pollution control programs. The body of epidemiological literature for health effects of particulate matter is large and robust, and is supported by good mechanistic understanding of how these pollutants can influence human health. Premature mortality and morbidity attributable to fossil fuel-related particulate matter persist in the U.S. and reduction in emissions from coal-fired power plants will have health benefits of the magnitude estimated within this report.

5.0 CONCLUSIONS

Retiring the nine coal-fired EGUs featured in this study would reduce emissions of $PM_{2.5}$ by 11,300 tons per year and sulfur dioxide and nitrogen oxides by 194,000 tons per year. As a consequence, $PM_{2.5}$ exposure will be reduced for millions of people in those states. For each year the emissions from the modeled EGUs are not released, approximately 180 lives will be extended in Michigan. But since the byproducts of coal-fired power plant emissions are dispersed over great distances, over 480 additional lives are lost annually in 39 other states influenced by these sources. Furthermore, we estimate that 30 lives would be lost annually in impacted areas of Canada. Other important health impacts, such as asthma morbidity, chronic bronchitis, hospital admissions due to pollutant exposures are associated with emissions from these EGUs. We estimate that the annual economic impacts associated with these health impacts to be approximately $1.5 billion in the State of Michigan and $5.4 nationwide.

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